X-641-73-333
PREPRINT

NASA TM X- 70513

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(NASA-TM-X-70513) COSMIC SOFT GAMMA-RAY BURSTS AND THE STELLAR SUPER-FLARE HYPOTHESIS (NASA) 14 p HC $3.00 CSCL 03B

N74-10760
Unclas
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NOVEMBER 1973

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

COSMIC SOFT GAMMA-RAY BURSTS AND THE STELLAR SUPER-FLARE HYPOTHESIS*

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*Contribution to the Los Alamos Conference on Transient Cosmic Gamma-Ray and X-ray Sources, September 20-21, 1973.

Recently, Klebesadel, Strong, and Olsen (1973) reported the exciting discovery of γ-ray bursts having a typical duration of the order of seconds and typical photon energies of the order of hundreds of keV. This observation has now been confirmed by Cline, Desai, Klebesadel, and Strong (1973) using the detector aboard the satellite IMP-6. This contribution is an expanded version of our previously published paper (Stecker and Frost 1973) suggesting a stellar superflare origin for these bursts.

Predictions of γ-ray bursts from supernovae have been made by Colgate (1968), but there are several difficulties in interpreting the observed bursts as originating in supernovae. In particular, the observed bursts have typical durations of the order of seconds with multiple bursts being common. They also appear to have soft exponential spectra with photon energies in the range of 150 to 250 keV. They have been observed to occur frequently with no apparent correlation with observed supernova events.

In contrast to the observed events, Colgate (1968) has predicted that γ-ray bursts from supernovae would have durations of the order of 10^{-5} s and hard power-law energy spectra with a characteristic energy of about 2 GeV. No correlation has been found between the observed bursts and observed extragalactic supernovae (Klebesadel et al.) and

the supernovae theory does not lead to a straight-forward explanation of multiple bursts. It thus appears to us probable that the observed bursts do not originate in supernovae, and that alternative possibilities for the origin of these bursts should be explored. We discuss here the alternative possibility that these outbursts are simply giant versions of the X-ray bursts typically seen in solar flares.

The observed γ-ray bursts bear a strong resemblance in many respects to the solar X-ray bursts observed recently with a 2-s time resolution (Frost, 1969; Kane, 1969). Figure 1 shows a representative nonthermal solar X-ray burst. This burst is dominated by two impulsive spikes, each about 10 s in duration. If a burst such as this were emitted by a star other than the sun, then only the narrowest parts of the burst might be detected above the background noise. Such bursts would appear to be shorter than solar bursts as is the case with the recently observed non-solar bursts. Thus there may be little intrinsic difference between the time-scales of solar bursts and the suggested stellar bursts at the source. In both cases, the time scale is much longer than that predicted for supernovae. The burst shown in Figure 2 is a single spike of less than 6 s duration.

The spectral characteristics of the nonsolar bursts have been measured by Cline et al. (1973). These spectral data from IMP-6 are found to be well described by an exponential spectrum of the form $I \propto e^{-E/E_o}$ with E_o being between 150 and 250 keV for a typical initial burst. Subsequent bursts in multiple-burst events appear to be softer with $E_o \sim$ 100 keV. The spike component of solar X-ray bursts could also fit an exponential energy spectrum with $E_o \sim 100$ keV (Frost, 1969). Although most solar bursts probably have an E_o somewhat less than 100 keV (but greater than 10 keV), we do not consider this a significant qualitative difference. The multiple spike characteristics seen in the nonsolar bursts are commonly seen in solar X-ray bursts as well.

We therefore consider it generally plausible that these bursts are caused by the bremsstrahlung of electrons accelerated to high energies in a stellar flare event. Assuming the acceleration to depend only on the strength of the effective field seen by the electrons, and not on electron energy, the final energy of the electron will be determined by the time the electron spends in the field. If we assume this acceleration time to be collisionally determined, the average time being T, the probability (P) of an electron being accelerated for time (t) is given by the distribution

$$dP/dt = T^{-1} e^{-t/T} \qquad (1)$$

The spectrum of accelerated electrons would then be of the form

$$I(E)\,dE \propto (dE/E_o)\,e^{-E/E_o} \tag{2}$$

where the mean acceleration rate is given by the constant E_o/T and E_o is the average electron energy. The resulting photon spectrum should then also approximate an exponential form. The above considerations are fairly general and it appears that they may be applicable to both solar and nonsolar bursts.

We conclude that the time scale, mean photon energy, and energy spectrum shape (therefore possibly the acceleration mechanism) for both the solar and nonsolar bursts are strikingly similar. There is so much similarity that it is a bit surprising considering that there is such a wide variation of surface conditions among the various stars in the galaxy. There does however appear to be one important difference. The nonsolar bursts that have been observed, which presumably must be both the closest and strongest of the nonsolar bursts, have a much greater intrinsic intensity than their solar counterparts. The strongest solar flares could have a total energy of $\sim 10^{32}$ erg (Bruzek, 1967). The bursts seen by Klebesadel et al. (1973) involve an energy flux of $\sim 10^{-5}$-10^{-4} erg/cm^2. Denoting this flux by ε, the X-ray energy at the source is given by

$$\mathcal{E} \approx 2\pi R^2 \varepsilon \qquad (3)$$

assuming the source flare radiates into 2π sr. Assuming $\varepsilon \approx 3 \times 10^{-5}$ erg/cm^2, a source at a distance R = 10 pc would have a typical total X-ray energy $\mathcal{E} \approx 2 \times 10^{35}$ erg and a corresponding total energy of 10^{38} to 10^{39} erg. A stellar burst of the type hypothesized here would then involve the acceleration of $\sim 10^6$ to 10^7 times more electrons than a strong solar flare. We may speculate that such an event might involve a star with a magnetic field strength $\sim 10^3$ times larger than the sun. Such fields may not be uncommon, particularly in stars earlier than F0, although the observational establishment of these fields is difficult and often impossible (Babcock, 1960). In addition, common white dwarf stars may have surface fields up to 3×10^7 G (Ostriker, 1970) so that they may be likely sources for these bursts. It seems reasonable to assume that such stars as are likely to produce the observed bursts should be near enough so that no concentration toward the galactic plane should be expected.

For example, the density of white dwarfs in the solar neighborhood is $\sim 5 \times 10^{-3}$ pc^{-3}. The Los Alamos group has observed 20 events over a 4 year period (Strong, et al. 1973) for a mean rate of 5 yr^{-1} or 2.5×10^{-4} events per white dwarf per year within 100 pc. The implication is that even

a small fraction of nearby white dwarfs with high magnetic fields and pathological surface conditions might account for the observed events. It seems to us also more likely that white dwarfs with high magnetic fields could produce a larger ratio of X-ray to optical flaring than other stars. Brecher and Morrison (1973) have suggested flaring in F stars, however, it is our opinion that F stars do not differ enough from our sun (similar magnetic fields and $\lesssim$ 6 times solar luminosity) to account for the overall large energy difference between solar and non-solar events.

Strong et al. (1973) have found 6 times as many bursts in the general direction away from the galactic center as towards the galactic center. Since the sun is on the inside of a spiral arm, Strong et al. (1973) argue that this evidence tends to support stellar origin within the galaxy in our local arm within ~ 100 pc of the sun. We thus tend to favor origin of the bursts in population I white dwarfs although we feel that other suggestions presented at this conference, such as those of Brecher and Morrison (1973) and Ramaty and Cohen (1973) are also interesting possibilities. We do not, however, feel that an extragalactic supernova origin for most of the reported events seems likely.

The stellar flare hypothesis immediately lends itself to various observational tests. Possible observational

consequences are: (1) repetitions of the bursts at the same position; (2) possible simultaneous radio bursts at the same position; (However, since we are considering here compact objects with very high magnetic fields, synchrotron self-absorption may eliminate this possibility.), and (3) γ-ray lines at 0.51 MeV (positron annihilation), 2.23 MeV ($n+p \rightarrow d+\gamma$), 4.4 MeV (C^{12*}) and 6.1 MeV (O^{16*}) as have been seen in strong solar flares (Chupp et al., 1973, see also Chapter VI.A). These lines may be present because the flare can accelerate protons as well as electrons so that various nuclear reactions may occur in the flare.

If the stellar flare hypothesis is verified, it may imply a significant source of low-energy cosmic-rays in the solar neighborhood (and throughout the galaxy), depending on the frequency and intensity of the flares.

The authors wish to thank Drs. T. Cline and R. Ramaty for valuable discussions and T. Cline for communicating his data to us prior to publication.

FIGURE CAPTIONS

Figure 1. A multiple solar X-ray burst observed on OSO-5 with a time structure similar to that observed for non-solar bursts.

Figure 2. A single solar X-ray burst also observed by OSO-5. This burst had a duration of less than 6 s.

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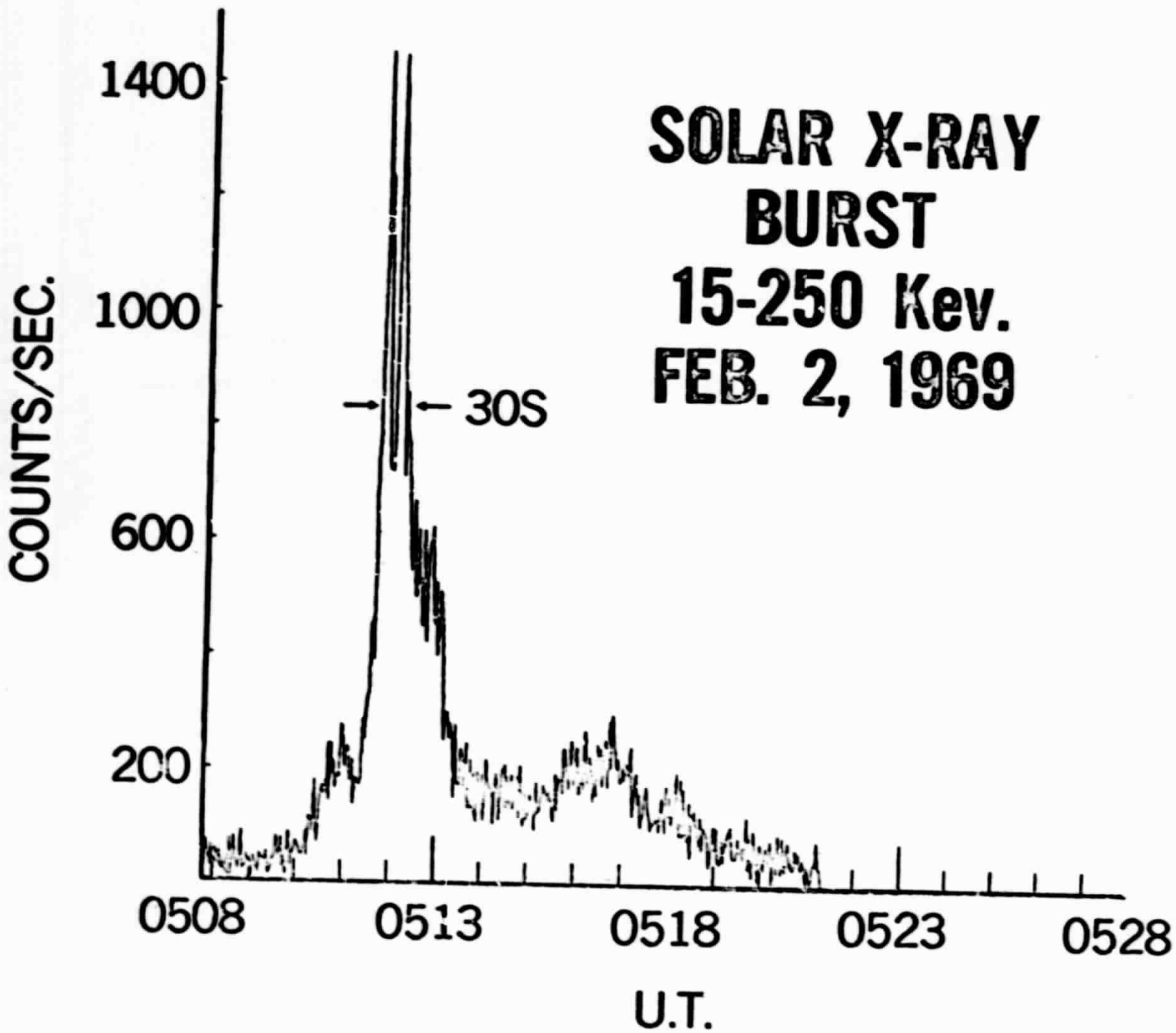
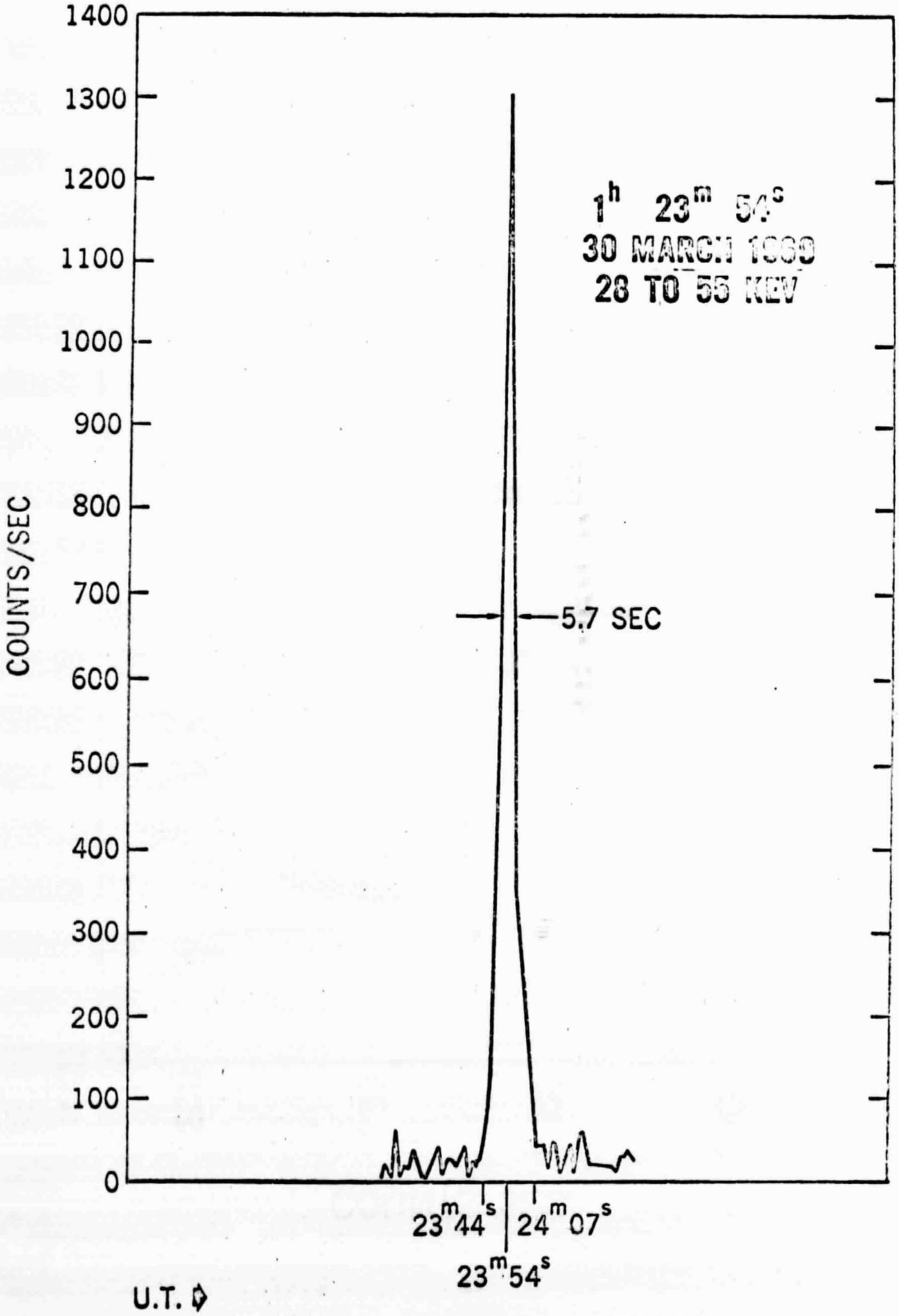
Figure 1. A solar X-ray burst observed on OSO-5 with a time structure similar to that observed for the non-solar bursts.

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